APPENDIX E

Partition Coefficients For Chromium(VI)

Appendix E

Partition Coefficients For Chromium(VI)

E.1.0 Background

The review of chromium K_d data obtained for a number of soils (summarized in Table E.1) indicated that a number of factors influence the adsorption behavior of chromium. These factors and their effects on chromium adsorption on soils and sediments were used as the basis for generating a look-up table. These factors are:

- Concentrations of Cr(III) in soil solutions are typically controlled by dissolution/precipitation reactions therefore, adsorption reactions are not significant in soil Cr(III) chemistry.

- Increasing pH decreases adsorption (decrease in K_d) of Cr(VI) on minerals and soils. The data are quantified for only a limited number of soils.

- The redox state of the soil affects chromium adsorption. Ferrous iron associated with iron oxide/hydroxide minerals in soils can reduce Cr(VI) which results in precipitation (higher K_d). Soils containing Mn oxides oxidize Cr(III) into Cr(VI) form thus resulting in lower K_d values. The relation between oxide/hydroxide contents of iron and manganese and their effects on K_d have not been adequately quantified except for a few soils.

- The presence of competing anions reduce Cr(VI) adsorption. The inhibiting effect varies in the order HPO_4^{2-}, $H_2PO_4^- \gg SO_4^{2-}$ CO_3^{2-}/HCO_3^- Cl^-, NO_3^-. These effects have been quantified as a function of pH for only 2 soils.

The factors which influence chromium adsorption were identified from the following sources of data. Experimental data for Cr(VI) adsorption onto iron oxyhydroxide and aluminum hydroxide minerals (Davis and Leckie, 1980; Griffin *et al.*, 1977; Leckie *et al.*, 1980; Rai *et al.*, 1986) indicate that adsorption increases with decreasing pH over the pH range 4 to 10. Such adsorption behavior is explained on the basis that these oxides show a decrease in the number of positively charged surface sites with increasing pH. Rai *et al.* (1986) investigated the adsorption behavior of Cr(VI) on amorphous iron oxide surfaces. The experiments were conducted with initial concentrations of 5×10^{-6} M Cr(VI). The results showed very high K_d values (478,630 ml/g) at lower pH values (5.65), and lower K_d values (6,607 ml/g) at higher pH values (7.80). In the presence of competing anions (SO_4: 2.5×10^{-3} M, solution in equilibrium with 3.5×10^{-3} atm CO_2), at the same pH values, the observed K_d values were 18,620 ml/g and 132 ml/g respectively leading to the conclusion that depending on concentration competing anions reduce Cr(VI) adsorption by at least an order of magnitude. Column experiments on 3 different soils conducted by Selim and Amacher (1988) confirmed the influence of soil pH on Cr(VI) adsorption. Cecil,

Windsor, and Olivier soils with pH values of 5.1, 5.4, and 6.4 exhibited chromium K_d values in the range ~9-100 ml/g, 2-10 ml/g, and ~1-3 ml/g respectively. Adsorption of Cr(VI) on 4 different subsoils was studied by Rai *et al.* (1988). The authors interpreted the results of these experiments using surface complexation models. Using their adsorption data, we calculated the K_d values for these soils. The data showed that 3 of the 4 soils studied exhibited decreasing K_d values with increasing pH. The K_d values for these soils were close to 1 ml/g at higher pH values (>8). At lower pH values (about 4.5) the K_d values were about 2 to 3 orders of magnitude greater than the values observed at higher pH values One of the soils with a very high natural pH value (10.5) however did not show any adsorption affinity ($K_d \leq 1$ ml/g) for Cr(VI).

The data regarding the effects of soil organic matter on Cr(VI) adsorption are rather sparse. In 1 study, Stollenwerk and Grove (1985) evaluated the effects of soil organic matter on adsorption of Cr(VI). Their results indicated that organic matter did not influence Cr(VI) adsorption properties. In another study, the Cr(VI) adsorption properties of an organic soil was examined by Wong *et al.* (1983). The chromium adsorption measurements on bottom, middle, and top layers of this soil produced K_d values of 346, 865, and 2,905 ml/g respectively. Also, another K_d measurement using an organic-rich fine sandy soil from the same area yielded a value of 1,729 ml/g.

A series of column (lysimeter) measurements involving Cr(VI) adsorption on 4 different layers of a sandy soil yielded average K_d values that ranged from 6 to 263 ml/g (Sheppard *et al.*, 1987). These measurements showed that coarse-textured soils tend to have lower K_d values as compared to fine-textured soils such as loam ($K_d \sim 1,000$ ml/g, Sheppard and Sheppard, 1987). Stollenwerk and Grove (1985) examined Cr(VI) adsorption on an alluvium from an aquifer in Telluride, Colorado. A K_d value of 5 ml/g was obtained for Cr(VI) adsorption on this alluvium. Removing organic matter from the soil did not significantly affect the K_d value. However, removing iron oxide and hydroxide coatings resulted in a K_d value of about 0.25 leading the authors to conclude that a major fraction of Cr(VI) adsorption capacity of this soil is due to its iron oxide and hydroxide content. Desorption experiments conducted on Cr adsorbed soil aged for 1.5 yrs indicated that over this time period, a fraction of Cr(VI) had been reduced to Cr(III) by ferrous iron and had probably coprecipitated with iron hydroxides.

Studies by Stollenwerk and Grove (1985) and Sheppard *et al.* (1987) using soils showed that K_d decreases as a function of increasing equilibrium concentration of Cr(VI). Another study conducted by Rai *et al.* (1988) on 4 different soils confirmed that K_d values decrease with increasing equilibrium Cr(VI) concentration.

Other studies also show that iron and manganese oxide contents of soils significantly affect the adsorption of Cr(VI) on soils (Korte *et al.*, 1976). However, these investigators did not publish either K_d values or any correlative relationships between K_d and the oxide contents. The adsorption data obtained by Rai *et al.* (1988) also showed that quantities of sodium dithionite-citrate-bicarbonate (DCB) extractable iron content of soils is a good indicator of a soil's ability to reduce Cr(VI) to Cr(III) oxidation state. The reduced Cr has been shown to coprecipitate with ferric hydroxide. Therefore, observed removal of Cr(VI) from solution when contacted with

chromium-reductive soils may stem from both adsorption and precipitation reaction. Similarly, Rai *et al.* (1988) also showed that certain soils containing manganese oxides may oxidize Cr(III) into Cr(VI). Depending on solution concentrations, the oxidized form (VI) of chromium may also precipitate in the form of $Ba(S,Cr)O_4$. Such complex geochemical behavior chromium in soils implies that depending on the properties of a soil, the measured K_d values may reflect both adsorption and precipitation reactions.

An evaluation of competing anions indicated that Cr(VI) adsorption was inhibited to the greatest extent by HPO_4^{2-} and $H_2PO_4^-$ ions and to a very small extent by Cl^- and NO_3^- ions. The data indicate that Cr(VI) adsorption was inhibited by anions in order of HPO_4^{2-}, $H_2PO_4^- >> SO_4^{2-} >> Cl^-$, NO_3^- (Leckie *et al.*, 1980; MacNaughton, 1977; Rai *et al.*, 1986; Rai *et al.*, 1988; Stollenwerk and Grove, 1985).

Table E.1. Summary of K_d values for Cr(VI) adsorption on soils.

Soil Description	Clay Content (wt.%)	Organic Carbon (wt.%)	Iron Oxide Content[1] (wt.%)	pH	CEC (meq/100g)	K_d (ml/g)	Experimental Parameters	Reference
Organic Soil (Muck) Top Layer, Florida	NR	7.05	NR	7.1	0.453	2905	NR	Wong et al. (1983)
Organic Soil (Muck) Middle Layer, Florida	NR	6.71	NR	7.2	0.409	865	NR	
Organic Soil (Muck) Bottom Layer, Florida	NR	2.79	NR	7.3	0.158	346	NR	
Hallandale Fine sand, Florida	NR	1.45	NR	8.2	0.113	1729	NR	
Alluvium, Telluride, Colorado	1	0.1	1.2	6.45	NR	1.7 - 52 5.3 5.6 0.25 2.35	Batch experiment, deionized water , eq. Cr conc. 1.4 - 0.0004 mmol/l Batch experiment, groundwater (pH: 6.8) Batch experiment, groundwater, Soil with org matter removed Batch experiment, groundwater, Soil with iron oxides removed Column experiment, groundwater, initial Cr conc. (0.01 mmol/l)	Stollenwerk and Grove (1985)
Loam (Chernozem), Canada	NR	NR	NR	NR	60	1000	NR	Sheppard and Sheppard (1987)
Sand (Regosol), Canada	NR	NR	NR	NR	1.6	100	NR	
Sand (Brunisol) organic surface layer (LFH-Ah)	NR	NR	NR	5.2	8.1	263, 6	Column experiments (lysimeter). Solutions: leachate, groundwater	Sheppard et al., 1987
Sand (Brunisol) upper layer (Ae)	NR	NR	NR	5.1	0.29	91, 35	Column experiments (lysimeter). Solutions:leachate, groundwater	
Sand (Brunisol) middle layer (Bfj)	NR	NR	NR	5.2	0.21	135,160	Column experiments (lysimeter). Solutions: leachate, groundwater	
Sand (Brunisol) lower layer (Bfjgj)	NR	NR	NR	6.2	0.17	53, 9	Column experiments (lysimeter). Solutions: leachate, groundwater	

[1] Total iron oxide (Fe_2O_3) content of soils. Values within parenthesis represent DCB extractable Fe content (mmol/g) of soils.

Table E.1. Continued.

Soil Description	Clay Content (wt.%)	Organic Carbon (wt.%)	Iron Oxide Content (wt.%)[1]	pH	CEC (meq/100g)	K_d (ml/g)	Experimental Parameters	Reference
Bayamon Series Soil	NR	NR	NR	NR	NR	8	NR	Ramirez et al. (1985)
Puerto RicoToa Series Soil	NR	NR	NR	NR	NR	110	NR	
Holton/Cloudland Series Soil (Btx horizon), Tenn.	34	0.05	5.90 (0.435)[a]	4.28	7.3	1585 to 1[2]	0.1 NaNO$_3$, pH: 4.45-9.84, Cr: 10^{-6} M	Rai et al. (1988)
Kenoma Series Soil (Bc+C horizon), Kansas	46	0.32	5.40 (0.162)[a]	6.94	28.4	28 to 1[2]	0.1 NaNO$_3$, pH: 5.62-8.42, Cr: 10^{-6} M	
Kenoma Series Soil (Bc+C horizon), Kansas	46	0.32	5.40 (0.162)[a]	6.94	28.4	12 to 1[2]	0.1 NaNO$_3$, pH: 5.02-7.49,Cr: 10^{-6} M, SO$_4$:$10^{-2.7}$ M , CO$_2$:$10^{-1.46}$ atm.	
Ocala Series Soil (C4 horizon), Nevada	31	0.14	4.38 (0.009)[a]	10.7	35.7	1 to 0[2]	0.1 NaNO$_3$, pH: 5.14-9.37, Cr: 10^{-6} M	
Cecil/Pacolet Series Soil (Bc horizon), N. Carolina	28	0.07	7.70 (0.266)[a]	5.33	4.4	646 to 1[2]	0.1 NaNO$_3$, pH: 4.49-9.29, Cr: 10^{-6} M	
Cecil/Pacolet Series Soil (Bc horizon), N. Carolina	28	0.07	7.70 (0.266)[a]	5.33	4.4	59 to 1[2]	0.1 NaNO$_3$, pH: 4.69-8.92, Cr: 10^{-6} M, SO$_4$: $10^{-2.7}$ M	
Cecil/Pacolet Series Soil (Bc horizon), N. Carolina	28	0.07	7.70 (0.266)[a]	5.33	4.4	427 to 0[2]	0.1 NaNO$_3$, pH: 4.49-9.29, Cr: 10^{-6} M, CO$_2$: $10^{-1.46}$ atm.	
Cecil Series soil	NR	0.24	10.2	5.1	3.72	~9 - 100	0.005 M Ca(NO$_3$)$_2$ background initial Cr. 1 - 100 mg/l	Selim and Amacher (1988)
Olivier Series soil	NR	0.99	1.14	6.4	8.31	~1 - 3	0.005 M Ca(NO$_3$)$_2$ background initial Cr 1 - 100 mg/l	
Windsor Series soil	NR	0.94	2.20	5.4	1.20	~2 - 10	0.005 M Ca(NO$_3$)$_2$ background initial Cr 1 - 100 mg/l	

NR = Not Reported.
[1] Total iron oxide (Fe$_2$O$_3$) content of soils. Values within parenthesis represent DCB extractable Fe content (mmol/g) of soils.
[2]K_d values listed from low to high pH conditions used for experiments.

E.6

E.2.0 Approach

The approach used to develop the look-up table was to identify the key parameters that control Cr(VI) adsorption reactions. From the data of Rai *et al.* (1988) and other studies of Cr(VI) adsorption on soils pH was identified as a key parameter. The data show (Table E.2) that the K_d values are significantly higher at lower pH values and decline with increasing pH. Also, K_d values for soils show a wider range at lower pH, but values for all soils converge as pH value approaches about 8. Another parameter which seems to influence soil adsorption of Cr(VI) is the capacity of soils to reduce Cr(VI) to Cr(III). Leckie *et al.* (1980) and Rai *et al.* (1988) showed that iron oxides in the soil reduce Cr(VI) to Cr(III) and precipitate Cr(III) as a $(Fe,Cr)(OH)_3$ mineral. Also, studies conducted by Rai *et al.* (1988) show that DCB extractable iron content is a good indicator as to whether a soil can reduce significant quantities of Cr(VI) which results in higher K_d values. It is important to note the total iron oxide content is a poor indicator of a soil's Cr(VI) reducing capacity and that DCB extractable iron better represents the fraction of iron content that would reduce Cr(VI) to Cr(III).   The data indicated that Holton/Cloudland soil with the highest concentrations of DCB extractable iron (0.435 mmol/g) exhibited higher K_d values than other soils which did not show an observable Cr(VI) reduction tendency.

Based on this information, 4 ranges of pH, which encompass the pH range of most natural soils, were selected for the look-up table (Table E.3). Within each pH range, 3 ranges of DCB extractable iron content were selected to represent the categories of soils that definitely reduce (≥ 0.3 mmol/g), probably reduce (0.26 to 0.29 mmol/g), and do not reduce (≤ 2.5 mmol/g) Cr(VI) to Cr(III) form. The range of K_d values to be expected within each of the 12 categories was estimated from the data listed in Table E.2. The variations of K_d values as a function of pH and DCB extractable iron as independent variables based on experimental data (Table E.2) is also shown as a 3-dimensional graph (Figure E.1). The graph indicates that soils with lower pH values and higher DCB extractable iron contents exhibit greater adsorption (higher K_d) of Cr(VI). At higher pH values (>7), Cr(VI) adsorption tends to be very low (very low K_d values) irrespective of DCB extractable iron content.   Similarly, soils which contain very low DCB extractable iron, adsorb very little Cr(VI) (very low K_d values) irrespective of soil pH values.

Additionally, Cr(VI) adsorption studies show that the presence of competing anions such as HPO_4^{2-}, $H_2PO_4^-$, SO_4^{2-}, CO_3^{2-}, and HCO_3^- will reduce the K_d values as compared to a noncompetitive adsorption process. The only available data set that can be used to assess the competing anion effect was developed by Rai *et al.* (1988). However, they used fixed concentrations of competing anions namely SO_4^{2-}, CO_3^{2-}, and HCO_3^- (fixed through a single selected partial pressure of CO_2) concentrations (Tables E.4 and E.5). Among these competing anions, SO_4^{2-} at about 3 orders of magnitude higher concentrations (2×10^{-3} M or 191.5 mg/l) than Cr(VI) concentration depressed Cr(VI) K_d values roughly by an order of magnitude as compared to noncompetitive adsorption. Therefore, the look-up table was developed on the assumption that K_d values of Cr(VI) would be reduced as soluble SO_4^{2-} concentrations increase from 0 to 2×10^{-3} M (or 191.5 mg/l).

Table E.2. Data from Rai *et al.* (1988) for the adsorption of Cr(VI) as a function of pH.

Kenoma Soil				Cecil/Pacolet Soil				Holton/Cloudland Soil				Ocala Soil			
pH	-log C (mol/m³)	-log S (mol/kg)	K_d (ml/g)	pH	-log C (mol/m³)	-log S (mol/kg)	K_d (ml/g)	pH	-log C (mol/m³)	-log S (mol/kg)	K_d (ml/g)	pH	-log C (mol/m³)	-log S (mol/kg)	K_d (ml/g)
8.42	3.03	6.25	1	9.26	3.05	5.66	2	9.84	3.03	6.33	1	9.37	3.02	6.56	0
7.71	3.05	5.84	2	9.29	3.05	5.88	1	8.67	3.04	6.11	1	9.40	3.03	6.05	1
7.70	3.04	5.97	1	8.57	3.11	5.34	6	8.60	3.08	5.60	3	8.94	3.02	7.71	0
7.35	3.09	5.54	4	7.80	3.30	5.00	20	8.29	3.09	5.53	4	8.94	3.02	6.67	0
7.40	3.08	5.59	3	7.41	3.44	4.89	35	8.27	3.07	5.70	2	8.67	3.04	6.00	1
7.20	3.03	5.36	5	7.38	3.46	4.88	38	8.08	3.11	5.45	5	8.61	3.02	6.36	0
7.16	3.13	5.37	6	6.99	3.66	4.81	71	7.55	3.30	5.04	18	8.33	3.04	6.00	1
6.89	3.16	5.27	8	6.94	3.65	4.81	69	7.15	3.44	4.92	33	8.30	3.03	6.07	1
6.92	3.15	5.29	7	6.67	3.79	4.78	102	7.05	3.51	4.89	42	7.56	3.03	6.14	1
6.70	3.23	5.13	13	6.49	3.79	4.78	102	6.96	3.60	4.85	56	7.53	3.02	6.48	0
6.47	3.26	5.09	15	6.19	3.99	4.75	174	6.88	3.61	4.85	58	7.53	3.02	6.86	0
6.02	3.36	4.98	24	6.16	3.94	4.75	155	6.26	4.26	4.74	331	7.07	3.03	6.25	1
6.02	3.35	4.99	23	5.89	4.08	4.74	219	6.20	4.25	4.74	324	7.18	3.03	6.19	1
5.61	3.39	4.95	28	5.84	4.06	4.74	209	5.40	4.55	4.73	661	6.92	3.03	6.21	1
5.62	3.40	4.95	28	5.46	4.19	4.73	288	5.39	4.63	4.73	794	6.88	3.02	6.48	0
				5.49	4.21	4.73	302	4.90	4.75	4.73	1047	6.61	3.03	6.12	1
				4.98	4.33	4.72	407	4.87	4.74	4.73	1023	5.71	3.02	6.68	0
				4.98	4.32	4.72	398	4.63	4.79	4.72	1175	5.14	3.04	6.01	1
				4.49	4.52	4.71	646	4.63	4.80	4.72	1202				
				4.49	4.39	4.72	468	4.51	4.85	4.72	1349				
								4.51	4.82	4.72	1259				
								4.50	4.88	4.72	1445				
								4.45	4.92	4.72	1585				

E.8

Table E.3. Estimated range of K_d values for Cr(VI) as a function of soil pH, extractable iron content, and soluble sulfate.

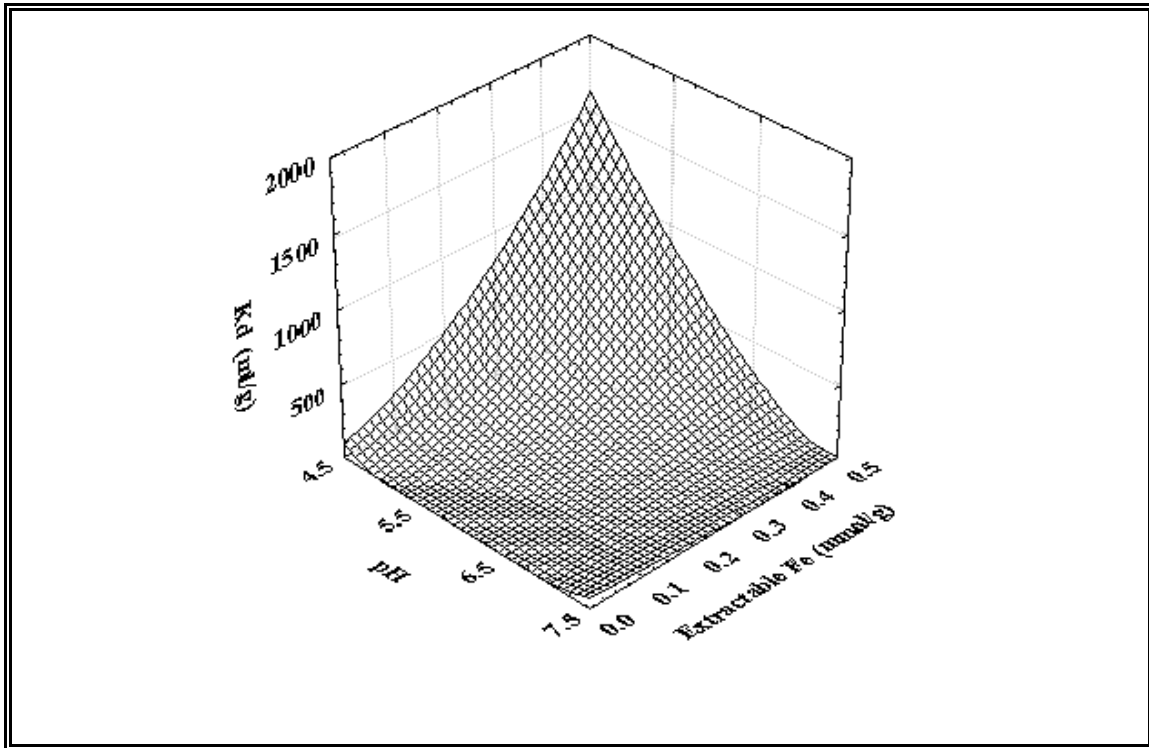| Soluble Sulfate Conc (mg/l)	K_d (ml/g)	pH												
		4.1 - 5.0			5.1 - 6.0			6.1 - 7.0			≥7.1			
		DCB Extractable Fe (mmol/g)			DCB Extractable Fe (mmol/g)			DCB Extractable Fe (mmol/g)			DCB Extractable Fe (mmol/g)			
		≤0.25	0.26 - 0.29	≥0.30	≤0.25	0.26 - 0.29	≥0.30	≤0.25	0.26 - 0.29	≥0.30	≤0.25	0.26 - 0.29	≥0.30	
0 - 1.9	Min	25	400	990	20	190	390	8	70	80	0	0	1	
	Max	35	700	1770	34	380	920	22	180	350	7	30	60	
2 - 18.9	Min	12	190	460	10	90	180	4	30	40	0	0	1	
	Max	15	330	820	15	180	430	10	80	160	3	14	30	
19 - 189	Min	5	90	210	4	40	80	2	15	20	0	0	0	
	Max	8	150	380	7	80	200	5	40	75	2	7	13	
≥190	Min	3	40	100	2	20	40	1	7	8	0	0	0	
	Max	4	70	180	3	40	90	2	20	35	1	3	6	

Figure E.1. Variation of K_d for Cr(VI) as a function of pH and DCB extractable iron content without the presence of competing anions.

E.3.0 Data Set for Soils

The data set used to develop the look-up table is from the adsorption data collected by Rai *et al.* (1988). The adsorption data for Cr(VI) as a function of pH developed for 4 well-characterized soils were used to calculate the K_d values (Table E.2). All 4 soil samples were obtained from subsurface horizons and characterized as to their pH, texture, CEC, organic and inorganic carbon contents, surface areas, extractable (hydroxylamine hydrochloride, and DCB) iron, manganese, aluminum, and silica, KOH extractable aluminum and silica, and clay mineralogy. Additionally, Cr oxidizing and reducing properties of these soils were also determined (Rai *et al.*, 1988). Effects of competing anions such as sulfate and carbonate on Cr(VI) adsorption were determined for 2 of the soils (Cecil/Pacolet, and Kehoma). The K_d values from competitive anion experiments were calculated (Tables E.4 and E.5) and used in developing the look-up table (Table E.3).

Table E.4. Data from Rai *et al.* (1988) on effects of competing anions on Cr(VI) adsorption on Cecil/Pacolet soil.

Cr(VI)[1]				Cr(VI) + Sulfate[1]				Cr(VI) + Carbonate[1]			
pH	-log C (mol/m³)	-log S (mol/kg)	K_d (ml/g)	pH	-log C (mol/m³)	-log S (mol/kg)	K_d (ml/g)	pH	-log C (mol/m³)	-log S (mol/kg)	K_d (ml/g)
9.26	3.05	5.66	2	8.92	3.05	6.27	1	9.62	3.05	6.88	0
9.29	3.05	5.88	1	8.38	3.07	5.71	2	9.15	3.05	6.79	0
8.57	3.11	5.34	6	8.38	3.04	5.70	2	9.01	3.06	6.35	1
7.80	3.30	5.00	20	7.70	3.12	5.28	7	7.92	3.06	6.12	1
7.41	3.44	4.89	35	7.67	3.12	5.28	7	7.95	3.06	6.10	1
7.38	3.46	4.88	38	7.37	3.19	5.11	12	7.53	3.08	5.85	2
6.99	3.66	4.81	71	7.24	3.23	5.09	14	7.52	3.07	6.06	1
6.94	3.65	4.81	69	6.85	3.34	4.95	24	7.19	3.12	5.55	4
6.67	3.79	4.78	102	6.76	3.37	4.96	26	7.31	3.10	5.67	3
6.49	3.79	4.78	102	6.58	3.43	4.92	32	7.22	3.12	5.55	4
6.19	3.99	4.75	174	6.56	3.34	4.95	25	6.99	3.13	5.48	4
6.16	3.94	4.75	155	6.15	3.55	4.85	50	6.70	3.22	5.21	10
5.89	4.08	4.74	219	6.15	3.51	4.88	43	6.68	3.21	5.24	9
5.84	4.06	4.74	209	5.75	3.58	4.82	58	5.84	3.65	4.87	60
5.46	4.19	4.73	288	5.79	3.56	4.86	51	6.08	3.54	4.91	43
5.49	4.21	4.73	302	5.35	3.60	4.83	59	5.12	4.11	4.78	214
4.98	4.33	4.72	407	5.33	3.59	4.84	57	5.12	4.14	4.78	229
4.98	4.32	4.72	398	4.68	3.55	4.86	49	4.76	4.20	4.78	263
4.49	4.52	4.71	646	4.69	3.47	4.86	41	4.75	4.11	4.78	214
4.49	4.39	4.72	468					4.33	4.39	4.76	427
								4.34	4.37	4.77	398

[1] Cr(VI) concentration: 10^{-6} M, Sulfate Concentration: $10^{-2.7}$ M, CO_2 : $10^{-1.6}$ atm.

Table E.5. Data from Rai *et al.* (1988) on effects of competing anions on Cr(VI) adsorption on Kenoma soil.

Cr(VI)[1]				Cr(VI) + Sulfate + Carbonate[1]			
pH	-log C (mol/m³)	-log S (mol/kg)	K_d (ml/g)	pH	-log C (mol/m³)	-log S (mol/kg)	K_d (ml/g)
8.42	3.03	6.25	1	7.49	3.06	6.22	1
7.71	3.05	5.84	2	7.42	3.06	6.35	1
7.70	3.04	5.97	1	7.3	3.07	5.98	1
7.35	3.09	5.54	4	7.38	3.08	5.9	2
7.40	3.08	5.59	3	7.08	3.08	5.83	2
7.20	3.03	5.36	5	6.93	3.1	5.64	3
7.16	3.13	5.37	6	6.49	3.15	5.43	5
6.89	3.16	5.27	8	6.52	3.16	5.39	6
6.92	3.15	5.29	7	6.32	3.17	5.33	7
6.70	3.23	5.13	13	6.32	3.18	5.31	7
6.47	3.26	5.09	15	5.97	3.23	5.21	10
6.02	3.36	4.98	24	5.97	3.21	5.25	9
6.02	3.35	4.99	23	5.7	3.23	5.2	11
5.61	3.39	4.95	28	5.69	3.24	5.18	11
5.62	3.40	4.95	28	5.54	3.24	5.19	11
				5.52	3.25	5.18	12
				5.03	3.18	5.32	7
				5.02	3.21	5.26	9

Cr(VI) concentration: 10^{-6} M, Sulfate Concentration: $10^{-2.7}$ M, CO_2 : $10^{-1.6}$ atm.

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